



COMMONWEALTH AGRICULTURAL BUREAUX

Biological Control Service

25 Years of Achievement



Introduction



Farnham House in 1927

The Farnham House laboratory, established in 1927, was the forerunner of the CIBC. It was active in Europe investigating temperate region pests, chiefly for Canada, and a mission was sent to the Caribbean which pioneered biological control of sugarcane stem borers. In 1940, when field work in Europe became impossible, it moved to Canada as the Imperial Parasite Service. Work in the Caribbean was resumed in 1945 from a base in Trinidad.

It acquired its present title, Commonwealth Institute of Biological Control, in 1951. The tropical work expanded with new Stations opening in India, Pakistan and later East Africa and as required sub-stations have operated in other areas, notably Argentina, Sabah, Java, Mexico, Ghana and Cameroun when needed. Now the major effort is directed at solving pest problems in developing countries but work for temperate regions remains substantial and is carried out mainly from the European Station in Switzerland.

Biological control results in the Commonwealth, and some other countries have been documented in the CIBC Technical Communications, and with the publication of USDA Agricultural Handbook No. 480 the results of much of the work completed worldwide up to about 1970 are now accessible. This booklet aims to draw attention to the achievements of the CIBC over the last 25 years. Much of the information is not yet readily accessible so that references are provided where possible, also other details indicating the value of the biological control attained. These evaluations, although in most instances only indicative, fully justify the effort expended to achieve effective self-sustaining and virtually permanent suppression of a number of intractable pests.

Also noticed are other successful introductions which have not yet been evaluated, or are too recent for the full impact to be apparent.

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Salvinia molesta

Contents

	Page
Citrus and other tropical fruits	5
Coconuts	7
Apples and other temperate fruits	8
Sugarcane and other graminaceous crops	8
Armyworms and cutworms	11
Pasture pests	11
Stable flies and other pest flies	11
Vegetable pests	12
Cotton	14
Forests and shade trees	15
Weeds	18
Waterweeds	23



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Citrus

and other tropical fruits

Many scale insects, particularly those on citrus, are readily controlled by natural enemies. The most recent to yield to biological control is the **Rufous scale** – *Selenaspis articulatus*. When other citrus scales in **Peru** had been suppressed by biological control, chemical control was still required against the rufous scale, diminishing the value of the biological controls. As it is a well-known pest in North and South America and extremely scarce in Africa, where it is believed to have originated, surveys were made in East Africa. After an extensive search sufficient parasitised scales were

found in 1971 for shipment to Peru. These yielded a new chalcidoid parasite, *Aphytis roseni* which was readily multiplied and was released in unsprayed citrus orchards from 1972–6. Parasitism rapidly reached over 90% of susceptible stages and soon the scale was held below the economic threshold. The operation cost 135,000 soles (about £1,025), brought benefits in savings on chemical control alone of 17 million soles (about £130,000) per year and provided an essential component for integrated control of citrus pests. (Beingolea G., O.D. (1977) *Noticiero Ent.* 1(i): 3–4).

There continues to be scope for extending biological control of other scales. Suppression of **Cottony cushion scale** – *Icerya purchasi* by *Rodolia cardinalis* is such a case. Since 1980, when success was apparent in California, the ladybird has been distributed to over 35 countries. The most recent

successful introductions by the CIBC have been into **Kerala** (India); the Caribbean Islands – **St. Kitts, Nevis, Montserrat, Antigua; Hong Kong; Ascension Island**. Under most conditions control is so good that the devastation to citrus and ornamentals, of which the scale is capable, is largely forgotten.

Another ladybird, *Cryptolaemus montrouzieri*, which is widely used against **mealybugs** – especially *Planococcus citri* – is still being distributed to new areas. The introduction into **St. Helena** in 1973 reduced mealybug infestations to a very low level and releases in **Saudi Arabia** in 1972–3 were immediately effective. However, this predator is difficult to establish permanently in areas where winters or extended dry seasons cause periodic shortages of prey. In such places annual releases are necessary to maintain control.

Successful introductions against other scale insects include:

Pest	Natural enemy	From	To	Year
<i>Ceroplastes rusci</i>	<i>Aneristus ceroplastae</i>	Pakistan	France	1973–4
<i>Coccus hesperidum</i>	<i>Metaphycus luteolus</i> <i>M. flavus</i>	California	USSR	1959
<i>Orthezia insignis</i>	<i>Hyperaspis</i> spp.	Trinidad	Barbados	1976–7
<i>Parlatoria pergrandii</i>	<i>Aphytis hispanicus</i> <i>Aspidiotiphagus citrinus</i>	India	Cook Is.	1973–4
<i>Pulvinaria psidii</i>	<i>Microterys kotinskyi</i>	California	Bermuda	1954
	<i>Cryptolaemus montrouzieri</i> <i>Azya luteipes</i>	Trinidad	Bermuda	1956–7



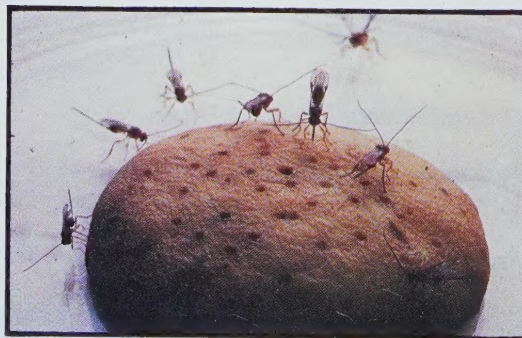
Orange blossom

Whiteflies, close relatives of scale insects, are also amenable to biological control. Very promising results are being achieved against *Dialeurodes citri*, which is now a widespread pest. As long ago as 1911 natural enemies were studied in India and among others an aphelinid parasite, *Prospaltella lahorensis*, was shipped to **California**. This was not followed up until 1968–70 when parasites were supplied by the CIBC Indian and Pakistan Stations. This time *P. lahorensis* from Pakistan, was successfully established but it was slow to disperse and has not yet had much impact. However, it was taken to **Florida** in 1977 and is spreading rapidly there. With this encouraging result, stock from California is being released in the **Mediterranean Basin**, but **Turkey** obtained fresh supplies from Pakistan in 1979. (Ru, N. & Sailer, R. I. (1979) *Florida Entomologist*, **62**: 59–65).

Another species, **Citrus blackfly** – *Aleurocanthus woglumi*, has spread from South East Asia to most citrus growing regions. Biological control carried out in Cuba in 1930 using an aphelinid *Eretmocerus serius* has since been attempted in some 30 other countries. Since *E. serius* is not always successful a second aphelinid, *Prospaltella opulenta*, has been distributed since 1949. The CIBC has been responsible for the introduction of one or both parasites into **Jamaica** (1964), **Barbados** (1964), **Grand Cayman Island** (1970) and the **Bahamas** (1972) in the Caribbean; the **Seychelles** (1955), **Kenya** (1966) and currently **Oman** in the Old World. In most countries, the results have been very satisfactory and biological control is widely accepted as the best means of suppressing this pest.

Successful introductions against other citrus pests include *Pteromalus puparum* sent from India to **Guam** in 1974 to control a butterfly pest, *Papilio polytes*. In campaigns against fruitflies, *Anastrepha* spp. *Opius humilis*, a braconid, from Trinidad is established in **Florida** (1969) and another species, *Biosteres longicaudatus* from Florida (1974), is now more abundant in **Trinidad** than native parasites. This parasite was also sent from Pakistan to **Zambia** (1977–79) and has been recovered from 5% *Dacus vertebratus*, a melon fly.

Barnacle scale – *Ceroplastes cirripediformis* – was, until 1972, a serious pest of passion fruit vines in **Hawaii**. The loss in yield during 1971 amounted to about US \$110,000. In 1967 an encyrtid wasp, *Coccidoxenus mexicanus* was introduced from Trinidad and liberated in an untreated area. Other parasites from other sources were also liberated. By October 1971, about 90% of the scales at the release site were parasitised mainly by *C. mexicanus*. From 1972 onwards only negligible to light infestations have been reported and pesticide applications are no longer needed. (Davis, C. J. (1974) *Proc. Hawaiian ent. Soc.* **21**: 355–358).



Opius longicaudatus ovipositing in peach

Banana skipper – *Erionota thrax*, a South East Asian leaf-rolling butterfly, appeared in **Mauritius** unexpectedly in 1970 and soon became a devastating pest. An egg parasite *Ooencyrtus erionotae* and a larval parasite *Apanteles erionotae* were sent from Sabah. They were very successful and damaged banana leaves have become a rare sight (J. Monty *in litt.*). When this butterfly appeared, equally unexpectedly, in **Hawaii**, the same parasites (from Thailand and not from the CIBC) were successful.

Souring beetles – *Carpophilus* spp. are a nuisance near pineapple fields in **Hawaii**. The CIBC has assisted in the campaign to control them and one predator, a staphylinid *Philonthalpus analis* from Trinidad, was established in 1975.



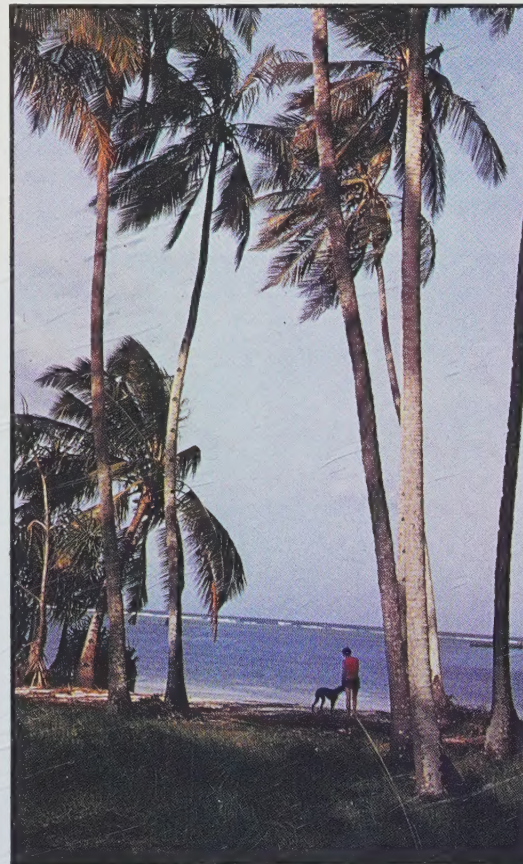
Banana leaf roller damage

Coconuts

Coconuts are another crop in which biological control has been particularly successful.

Coconut Leaf-miner – *Promecotheca cumingi*, a hispine leaf-miner from south east Asia, was first found in **Sri Lanka** south of Colombo in early 1970. The CIBC was soon asked about possibilities of biological control, which following previous successful control of related pests in Fiji and New Guinea, appeared very promising. Parasite shipments were obtained from Fiji, Singapore and Indonesia. Two eulophid larval parasites were bred and released; *Pediobius parvulus* which had been successful elsewhere, and also *Dimmockia javana*. At the time of the releases in 1971–2 some 10,400 ha were infested. Although both parasites became established, surprisingly it was *D. javana* which multiplied astronomically and virtually eliminated *P. cumingi* by the end of 1974. Costly spraying equipment, specially imported as an insurance against failure, was never used. The operations, including the spraying equipment, cost almost £20,000 and the shipments a further £500. As there are 440,000 ha of coconuts in Sri Lanka and losses of nuts in the infested area reached 85%, even taking a conservative estimate of 50% overall, had the pest not been controlled monetary loss could have reached £6.9 million per year, and the cost of chemical to spray the whole area once would have amounted to almost £27 million. Thus, timely intervention prevented a disaster. (Dharmadikari, P. R. *et al.* (1977) *Entomophaga*, 22: 3–18.)

Since the successful control of **Coconut scale** – *Aspidiotus destructor* – in Fiji in 1928 by a coccinellid, *Cryptognatha nodiceps* from Trinidad, it has become a first choice for biological control. A dramatic example, involving the CIBC, was achieved in **Principe** following the invasion of the



Coconut palms

island by the coconut scale in 1962. Coccinellids from Trinidad, principally *C. nodiceps*, were released in 1955. *C. nodiceps* rapidly brought the scale under control so that by 1958 copra production had returned to normal after falling by 80% during the outbreak when copra valued at £72,000 per annum was lost. (Simmonds, F. J. (1960) *Bull. ent. Res.* 51: 223–237). *C. nodiceps* and *Azya trinitatis* were sent to Jamaica in 1957, and *C. nodiceps* to St. Kitts and Nevis in 1970. They are established and in **St. Kitts** a considerable decline in scale attack followed.

In the lengthy campaign against **Rhinoceros beetles**, *Oryctes rhinoceros* predatory beetles, *Pheropsophus* spp. from India, were established in **Mauritius** in 1961 and an assassin bug, *Platymeris laevicollis* from Zanzibar, in the **Laccadive Islands** in 1968. Since then attempts to use insect predators have been superseded by virus and fungus diseases which are very effective.

Apples

and other temperate fruits

Fewer successes have been achieved against fruit pests in temperate regions, but a pioneering success was achieved against the **Woolly apple aphid** – *Eriosoma lanigerum*. Since 1920 when successful results began to be reported, following introductions of *Aphelinus mali* from the central USA to Uruguay and France, the parasite has been distributed to about 30 countries. The results have been variable, depending on climate and whether the aphid colonises the roots where the parasite cannot reach it, but in many countries the pest has been reduced to negligible importance. The Farnham House Laboratory began to distribute colonies shortly after its establishment. Since then the CIBC has been involved in many introductions

of *A. mali*, one of the most recent and successful, being in **Assam**, India, in 1963.

San Jose scale – *Quadraspidiotus perniciosus* a pest of fruit trees and ornamentals, which is believed to have come from the Far East, has spread to most parts of the world during the past 100 years. It has long been a target of success where insecticides have not prevented establishment of aphelinid parasites. The CIBC has arranged introductions from California into India and Pakistan since 1960. Strains of *Prospaltella perniciosi* are established in Pakistan without benefit, but in **India** (Uttar Pradesh and Kashmir), *P. perniciosi* and *Aphytis diaspidis* are reported to achieve high levels of parasitism.



Apple woolly aphid on *Pyracantha*

Sugarcane

and other graminaceous crops

Biological control is extensively used against sugarcane pests which are difficult to control by other means. In most areas **stem borers** are key pests and have received most attention.

In the New World *Diatraea saccharalis* is the most notorious of a series of moth borers of sugarcane and other graminaceous crops. Pioneering work was carried out by J. G. Myers of the Farnham House Laboratory and H. A. Jaynes from the USA in the 1930s on the native tachinid parasites and some successes achieved with their redistribution. This work was resumed by the CIBC after the end of World War II and further successes reported, chiefly in the Caribbean Islands. However, success in **Barbados** was not achieved until 1966, when trials were made with parasites of related Asian borers, and one of them a braconid, *Apanteles flavipes*, became established. It spread rapidly and at the same time one of the flies, *Lixophaga diatraeae* introduced previously, began to build up in numbers. By 1970 the two parasites had reduced damage from around 16% cane joints bored to less than 6% and have maintained satisfactory control since. (Alam, M. M. *et al.* (1971) *Entomophaga*, **16**: 151–158.)

News of this success led to a demand for the braconid which the CIBC has satisfied so that it is now firmly established in Florida, Texas, St. Kitts, Trinidad, Panama, Guyana, Venezuela, Colombia, Brazil and Peru. In the USA, the only major growing area where chemical control is routine, *A. flavipes* is being integrated into the control programme. (Fuchs, T. W. *et al.* (1979) *Entomophaga*, **24**: 109–114.) In **Brazil** large scale campaigns have been mounted based on mass rearing. Results suggest that *A. flavipes* is becoming established and is achieving high rates of

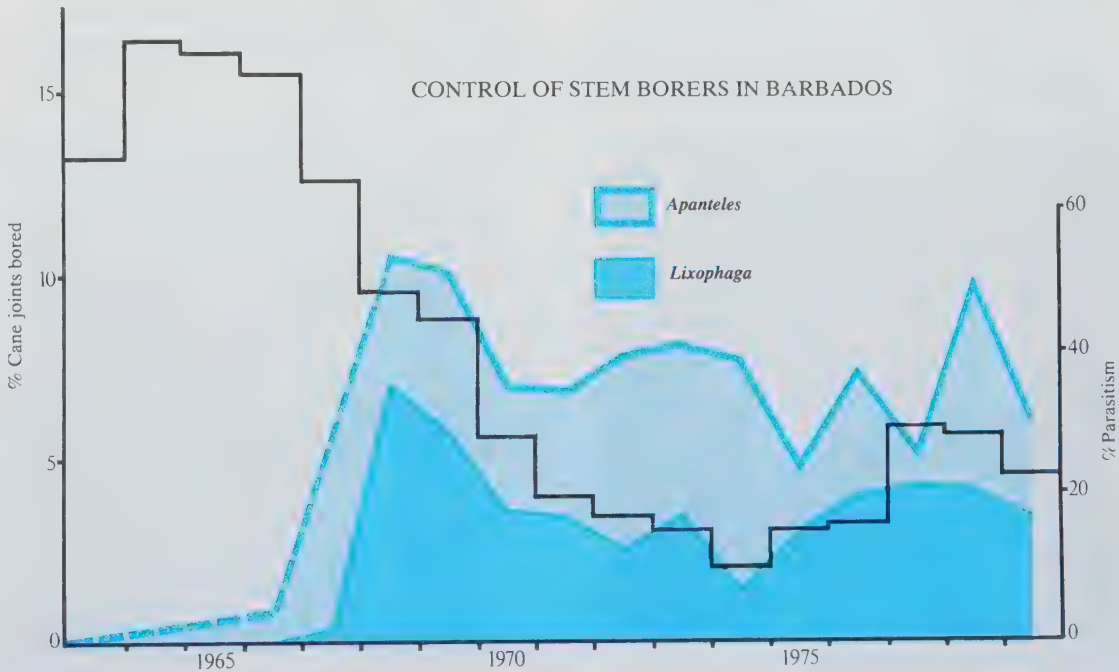
parasitism. At one location releases of 5,297 wasps per hectare at a cost of US \$10 resulted in a net profit of \$50 per hectare in increased yield. (Mendes, A. C. *et al.* (1979) *Proc. 1 Congr. Brasil. Soc. Sug. Technol. Maceio*, 25pp.)

So far biological control has been less successful against Old World stemborers – *Chilo* spp. and *Sesamia* spp., but some progress has been made. In Pakistan a Japanese strain of *Apanteles flavipes* was established against *Chilo partellus* but as it suffered severely each winter it was for over a decade unable to reach effective levels of parasitism until the end of the season. Recently parasitism has started to build up two months earlier giving hope that it may eventually achieve control. (Alam, M. M. *et al.* (1972) *Tech. Bull. CIBC* No. 15: 1–10.)

Studies in East Africa made available a useful eulophid pupal parasite, *Pediobius furvus*, which has successfully controlled *Sesamia calamistis* in **Madagascar** following releases in 1968. Trials in other areas have had disappointing results but are worth pursuing. (Appert, J. & Ranaivosoa, H. (1971) *Bull. Madagascar* 21: 539–541.)

Other successful introductions include:

Stemborer	Parasite	From	To	Date
<i>Chilo</i> spp.	<i>Trichogramma</i> spp.	Various Colombia	India	1963
	<i>Telenomus alecto</i>		India	1963
<i>C. sacchariphagus</i>	<i>Trichospilus diatraeae</i>	India	Mauritius	1965
<i>Scirpophaga nivella</i>	<i>Isotima javensis</i>	India	Taiwan	1962



The **White scale** – *Aulacaspis tegalensis* a specific pest of sugarcane has spread from its original home in Indonesia to the Indian Ocean islands and East Africa. Studies by the Mauritius Sugar Industry Research Institute and CIBC led to redistribution of natural enemies and substantial biological control in some places. The East African eulophid parasite, *Physcus seminotus*, and the Indonesian aphelinid, *Aphytis* sp., are now naturalised in **Mauritius** where they achieve high levels of parasitism. Assessment of their impact has not been feasible.

The scale invaded the Tanganyika Planting Company estate, near Moshi during 1969 and rapidly caused calamitous losses up to 25% recoverable sugar with added problems from death of canes and reduced milling quality. The coccinellid, *Lindorus lophanthae* abundant but

ineffective under Mauritius conditions, was introduced from that island in mid-1971. By the end of 1972 it had spread throughout the estate and brought the situation under control. Although there are annual cyclical fluctuations in scale abundance sometimes leading to minor outbreaks the scale has been satisfactorily contained. The difference in performance of *L. lophanthae* is attributed to continuous harvesting of cane in **Tanzania** which does not upset the balance between predator and host. (Williams, J. R. & Greathead, D. J. (1973) *PANS* 19: 353–367.) The estate management calculated that the cost of this achievement amounted to 87,500 Tanzanian shillings (£5,120) including payments to CIBC, consultants and local costs, while the benefit was 2 million Tanzanian shillings (£118,000) per year during the first four years.

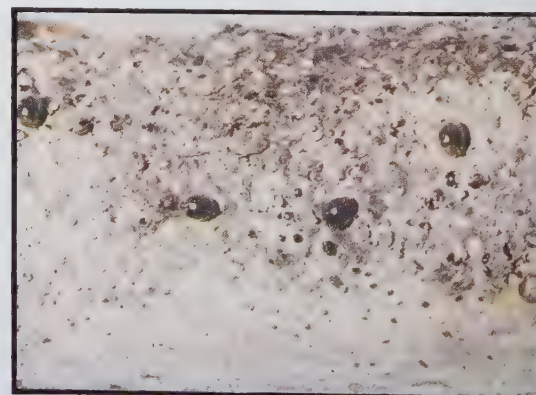
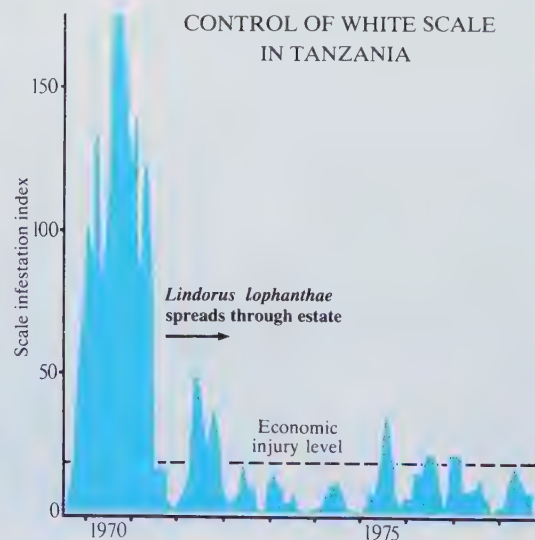
Another scale, *Melanaspis glomerata* is an important pest in India. Ladybirds – *Sticholotis madagassa* from Réunion, *L. lophanthae* from Mauritius and *Chilocorus cacti* from the USA – have recently been established and results are awaited.

The **Pink sugarcane mealybug** – *Saccharicoccus sacchari* – is now widespread and is a damaging pest in some areas. An encyrtid parasite, *Anagyrus saccharicola*, which seems to suppress it in Africa was sent from Uganda to **Barbados** in 1971 where it achieved excellent control and from there to St. Kitts. A coccinellid, *Hyperaspis trilineata* was also sent from Barbados to St. Kitts and is established. Similarly *Cryptolaemus montrouzieri* from Trinidad was established in the Bahamas in 1969.

A **Sugarcane leafhopper** – *Pyrilla pusilla* – can be a troublesome pest in **Pakistan**. In 1975 a predatory moth, *Epipyrops melanoleuca*, which is present in the Lyallpur area was effectively established in the Peshawar area, where it was previously absent.



White scale with coccinellid pupae



Lindorus lophanthae on *Melanaspis glomerata*

Armyworms

and cutworms

In a programme to reduce the damage caused by noctuid moths in **New Zealand** parasites were imported from Pakistan in 1971. One of them, a braconid *Apanteles ruficrus*, was already present but did not attack the target pests, however the Pakistan strain showed promise against *Mythimna separata*. So some 40,000 were released in 1971–2 and by 1975 rates of parasitism of *M. separata* in maize reached 80% and there was a spectacular reduction in damage. Besides savings of the order of US \$500,000 on insecticides and their application in 1974–75, New Zealand, instead of importing maize, exported 60–80,000 tonnes and earned an additional several million dollars. The grazier also profited considerably in the absence of armyworm outbreaks but the savings are difficult to assess. The amount spent by the CIBC was about \$1,700 and the total cost of the operation in New Zealand was not more than \$20,000, while in 1974–75 season the benefits have been estimated at more than \$10,000,000. Similar gains have been experienced in subsequent years despite ideal conditions for outbreaks of this pest and record maize crops have been harvested. (Mohyuddin, A. I. & Shah, S. (1977) *Entomophaga*, **22**: 331–333. Cumber, R. A. *et al.* (1977) *N.Z. J. agric. Res.* **20**: 255–258.)

A culture of a scelionid egg-parasite of *Spodoptera* spp., *Telenomus remus* from New Guinea, has been held at the Indian Station for several years. When material was sent to **Barbados** in 1971 the parasite rapidly became established achieving rates of parasitism of up to 100% particularly on *S. frugiperda*. It is reported to have materially abated damage to cotton, maize, sugarcane, onions and other crops. Since then it has been successfully established in Montserrat and also in Andhra Pradesh and Bangalore in India.

Pasture pests

Rhodes grass scale – *Antonina graminis* – became a damaging pest of pasture grasses in the Americas. A parasite, *Neodusmetia sangwani*, which is common in Africa and Asia, was sent to Texas in 1959 by the Indian Station. It was soon established but the wingless females did not disperse well so parasitized scales were distributed by aircraft. An assessment in 1978 records a complete success. Recovery of the 30% loss in carrying capacity of native ranges has provided a benefit to the ranching community of \$177 million per year in profits on calf sales and reduced maintenance costs on turf grasses, a saving of \$17 million per year. The total cost of the project did not exceed \$200,000. (Dean, H. A. *et al.* (1979) *Bull. ent. Soc. Am.* **25**: 262–267.) It is now being used in other countries and has been established in northern Brazil and Bermuda.

The **Clover casebearer** – *Coleophora alcyonipennella* is a pest in **New Zealand**. *Bracon variegator*, a parasite introduced from the European Station in 1961 became established in several areas of Nelson Province, and when evaluated in 1966–9 it was causing a noticeable decline in the pest population density. (Thomas, W. P. (1969) *N.Z. J. Sci.* **12**: 43–53.)

In an attempt to control **leatherjackets** – *Tipula paludosa* – in **British Columbia**, a tachinid fly, *Siphona geniculata* was successfully introduced from central Europe in 1972–3.

Stable flies

and other pest flies

The CIBC is contributing to the worldwide surveys of natural enemies of dung and refuse breeding flies initiated by the University of California, which are providing the basic information necessary for management of these cosmopolitan pests. Effective pest management systems are now being developed in the USA for use on livestock farms.

In **Mauritius** stableflies are a long standing problem on which biological control is making an impact. Pteromalid puparial parasites of flies breeding in dung, shipped from Trinidad, were released for several years from 1966. *Spalangia* spp., *Muscidifurax raptor* and *Pachycrepoides vindemiae* became established and are credited with abatement of the problem in areas where *Stomoxys calcitrans* was the pest species. However, *S. nigra*, which breeds in rotting vegetation, especially sugarcane tops at harvest, was not controlled. Surveys in Uganda revealed parasites specific to this habitat which were shipped in 1972. The most abundant, *Tachinaephagus stomoxida* was multiplied and released widely. Provided there are no heavy rains during the sugarcane harvest, which intensify fly breeding, it is able to maintain control (J. Monty, *in litt.*).

Vegetable pests

Biological control is usually more difficult to achieve in annual crops and smallholdings where the habitat is unstable and chemical usage is heavy, but in spite of these constraints some important successes have been achieved. In some instances their potential will only be fully realised when other pests, against which insecticides must still be applied, have been suppressed by other means.

Beanfly – *Ophiomyia phaseoli* a widespread pest in the Old World tropics of many of the most widely grown legumes, reached the **Hawaiian Islands** in 1968. Studies on its parasites had already been made in Uganda enabling a rapid response. The braconid parasites *Opius phaseoli* and *O. importatus* were despatched in 1969 and by the end of 1970 were firmly established and had reduced

infestations to negligible proportions. As beans are a back-yard horticultural crop it is impossible to quantify the benefit but the operation is rated an outstanding success by the Department of Agriculture. Subsequently the *Opius* spp. were sent to Brunei and establishment was reported, but no details of the results are available. These parasites deserve more widespread use as they evidently establish easily: *O. importatus*, the most important in Hawaii, is only known from East Africa while *O. phaseoli* has been found only as far east as India. (Greathead, D. J. (1975) *Entomophaga* 20: 313–316.)



Photographic evidence of Beanfly damage, Uganda

Podborers, chiefly moth caterpillars, are important limiting factors in the production of legumes throughout the tropics. Pigeon pea is usually one of the most seriously affected. The problem was studied in Trinidad on behalf of **Mauritius** and shipments of seven species of parasites were begun in 1953. This work led to the establishment of two of them (*Bracon cajani* and *Eiphosoma annulatum*). Estimates of the result vary but it is generally agreed that a substantial reduction of the main pests (*Etiella zinkenella* and *Maruca testulalis*) was obtained. (Greathead, D. J. (1971) *Tech. Commun. CIBC* No. 5: 69–70.) This has led to requests for parasites from other areas and a release programme is being conducted currently in Fiji. Since legumes are an important source of vegetable protein this work merits expansion to other areas and crops to make best use of known parasites and to find others which in some regions or on other crops may be more effective.

Biological control of the pantropical **Green stink-bug** – *Nezara viridula* has been successful in several areas using strains of the widespread sceleronid egg-parasite *Asolcus basalus*, notably in Australia. This parasite, sent from Australia, and two tachinid flies have given complete control in **Hawaii**. Of the two flies *Trichopoda pilipes* from Montserrat and Antigua, supplied by the CIBC in 1962, is the more efficient, the other, *T. pennipes*, came from Florida. Once a serious pest of fruits, vegetables and ornamentals, it is now a rare insect and its control saves an estimated one million dollars per annum in lost produce. (G. Funasaki, *in litt.*)

The **Potato tuber moth** – *Phthorimaea operculella* is now a pest throughout tropical and subtropical regions where potatoes or tobacco are grown. Biological control attempts were sporadic and largely unsuccessful until parasites from its original home in South America began to be distributed from California and later India by the

CIBC. Although release programmes have been carried out in at least 10 countries using this material, results are not available from all and in many are confounded by heavy routine use of pesticides. The most clearcut success has been achieved in **Zambia** where the establishment of five species in 1969–70 raised the potato yield by 22%–25% and an Agricultural Department economist estimated in 1972 that the cost was £15,363 with a discounted gain to 1980 valued at £235,380. In **Cyprus** a programme of introductions started in 1965 resulted in the establishment of at least 3 species which in 1975 were estimated by the Ministry of Agriculture to have saved 4,200 tonnes of potatoes. Partial control is reported from Australia and parasites are known to be established in India, Mauritius, Madagascar, St. Helena, New Zealand, South Africa and the USA. The most successful species are usually *Copidosoma koehleri*, and *Apanteles subandinus* from South America. (Cruikshank, S. & Ahmed, F. (1973) *Tech. Bull. CIBC* No. 16: 147–162.)

Wherever cabbages or related crops are grown the **Diamondback moth** – *Plutella xylostella* – is likely to be present and in the warmer parts of the world it is often a key pest. Effective parasites are present in some areas and gave promising results when established in Australia and New Zealand. Their distribution to other areas has been promoted by the CIBC. Introduction of *Apanteles plutellae* during the last decade has succeeded in at least Barbados, Antigua, Montserrat, St. Kitts, Trinidad and probably other West Indian islands and in Zambia where *Thyraella collaris* is also established. A third parasite, *Tetrastichus sokolowskii* is established in Barbados and Trinidad. In **Barbados** and **Zambia** rates of parasitism over 80% are reported and confirm that these parasites are capable of controlling the pest. However, where insecticides are applied against other pests biological control is suppressed. Distribution of diamondback moth parasites continues.



Green stink-bug with eggs of *Trichopoda pilipes*



Agathis unicolor ovipositing in Potato tuber moth



Thyraella collaris ovipositing in Diamondback moth

Cotton

Mexican bean-beetle – *Epilachna varivestis* has been extending its range into the USA since 1920. A eulophid parasite, *Pediobius foveolatus* was sent from India and first released in Maryland in 1973. Although it cannot survive the winter innoculative releases in spring enable excellent control because the parasite has a high fecundity and efficient searching ability, allowing it to achieve rates of parasitism of 80%–100% early in the season and prevent pest build-up. (Stevens, L. M. *et al.* (1975) *Environ. Ent.* 4: 947–952.)

The **Giant African snail** – *Achatina fulica* has been spread from its native home on the East African coasts through most of the islands of the Indian and Pacific Oceans and the surrounding countries during the past century and a half. Biological control was pioneered by Hawaii in 1948 and resulted in the import of predatory snails from Africa (*Gonaxis* spp.) and Florida (*Euglandina rosea*). These were sufficiently successful for other countries to wish to attempt introductions. The CIBC has assisted in distributing *E. rosea* and the most successful of the African species, *G. quadrilateralis*. As a result *E. rosea* has become quite abundant in **Mauritius** and is established in India, while *G. quadrilateralis* is well established in Malaysia and the Seychelles. Accounts of their impact vary but in most countries they are generally believed to have had some beneficial effect.

Releases have also been made against other pest snails; notably against *Otala lactea* in **Bermuda** where establishment of *E. rosea* is estimated to save vegetable growers planting crucifers some \$2,000 per year. (Simmonds, F. J. & Hughes, I. W. (1963) *Entomophaga*, 8: 219–222.)

Two braconid parasites of **cotton bollworm** larvae (*Bracon kirkpatricki* and *Chelonus blackburni*) introduced into **India** through the CIBC, were recovered in 1976 in the Hissar District (Harayana): *C. blackburni* is also being recovered in other states. Another species, the egg-parasite *Trichogramma brasiliensis*, is being detected in several areas. In Hissar *C. blackburni* and *T. brasiliensis* were credited with an 8%–10% reduction in damaged bolls in 1977–8 and 15% in

1978–9, and also with a 10% reduction in damage by the *Heliothis armigera* on chick pea during 1977–8. Inundative releases on *T. brasiliensis* in the Ludhiana District (Punjab) are reported to have reduced bollworm incidence from 70% to 30% during 1978. These results suggest that parasites are capable of providing an important input into the integrated pest management schemes now being developed in many cotton growing regions.



Bracon kirkpatricki feeding on Pink bollworm

Forests

and shade trees

Major effort has been made by the CIBC for many years to find and supply natural enemies of European pests of forest trees accidentally established in Canada, the USA and New Zealand.

Substantial control of **Larch sawfly** – *Pristiphora erichsonii* – in **Canada** followed the introduction of the ichneumonid *Mesoleius tenthredinis* from Europe between 1910 and 1913. The development of a host strain encapsulating the parasite led to outbreaks in the 1940s and moderate to severe defoliation in many locations for over six consecutive years prompted renewed effort at biological control. Two out of six parasites introduced from Europe and Japan by the CIBC became established during 1961; a Bavarian strain of *M. tenthredinis* with a marked ability to avoid encapsulation and the ichneumonid *Olesicampe benefactor*. Both increased rapidly and the ensuing high rates of parasitism led to a decline in host density. The second also spread at a rapid rate, is now widespread in central Canada, and has been established elsewhere in Canada and in the USA.



Larch sawfly larvae

At the original release sites larch sawfly has virtually disappeared. Analysis of population data indicates that were it not for *O. benefactor*, and in spite of high rates of attack by a hyperparasite, outbreaks would have occurred since the first release. (Turnock, W. J. & Muldrew, J. A. (1971) *Tech. Commun. CIBC* No. 4: 175–194.)

Biological control against the **European pine sawfly** – *Neodiprion sertifer* – in **Ontario**, was started in the 1930s when eight parasites were introduced. Three that became established – the eulophid *Dahlbominus fuscipennis*, and the ichneumonids *Exenterus amictorius* and *Pleolophus basizonus* – are now regularly recovered in large numbers and are widely distributed. As a result of new efforts during the last 20 years, the ichneumonid, *Lophyrophlectus luteator* introduced from Europe between 1962 and 1972, became established immediately. At one locality it achieved a rate of parasitism of 28% three years after release. In 1973 it had spread about up to 120 km and in 1976 was present wherever *N. sertifer* was found in south eastern Ontario. *Dipriocampe diprioni* an eulophid egg-parasite imported in 1974, which was recovered after the first full field generation, shows good promise of success. (Rose, A. H. (1976) *Can. Ent.* 108: 1395–1398.)

Biological control of the **Larch casebearer** – *Coleophora laricella* in the eastern USA attempted in the 1930s–1950s was successful when the main parasites, a braconid *Agathis pumila* and an eulophid *Chrysocharis laricinellae*, were introduced from central Europe. A second major effort started in 1960 when *A. pumila* was introduced and established in the northwest.

At some plots in **Idaho** it achieved 68% parasitism within 8 years and densities of over-wintering casebearer decreased from 278 larvae per 100 fascicles to 20, but on other plots it did not increase. From 1972–9 more parasites were released in the northwest, and *A. pumila*, *C. laricinellae* and a eulophid *Elachertus argissa* were established. Present low host densities in **Montana** are attributed to the combined action of the first two species. However, the impact is difficult to



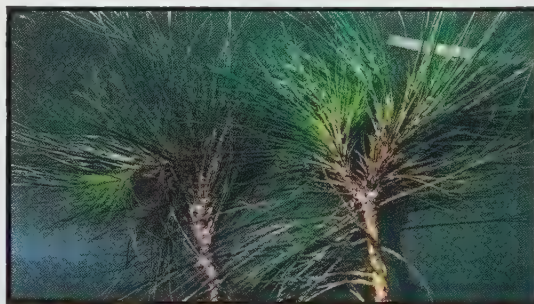
European pine sawfly

estimate as documentation of host density over the years is inadequate but the potential impact of uncontrolled casebearer on increment over the 2.7 million acres of rest land dominated by larch was estimated (based on stumpage prices) to amount to \$3–10 million each year. Thus, the economic benefit of even partially successful biological control is clear.

The intensive campaign against the **Balsam woolly aphid**, *Adelges piceae*, in North America has been very disappointing. Numerous species from Europe, the Himalayas and Japan were introduced as a result of extensive surveys and ecological studies. Only five became established (the coccinellids, *Aphidecta oblitterata* and *Pullus impexus*; a detodontid, *Laricobius erichsonii*; a chamaemyiid, *Cremifania nigrocellulata*; a cecidomyiid, *Aphidoletes thompsoni*). Of these *L. erichsonii* alone is of any practical value.

This work revealed predators for use against the **Pine woolly aphid**, *Pineus pini*, which appeared as a devastating pest in Kenya and Hawaii, in the mid-1960s. So far an anthocorid, *Tetrupleps raoi*, is established in Kenya (1975) and a chamaemyiid, *Leucopis nigriluna*, on the island of **Hawaii** (1972) where it has brought infestation under control. These predators from the Himalayas will be supplemented by others.

Promising establishments are also reported against **Pine bark beetles** – *Hylastes ater* – in **New Zealand**. They are a pteromalid parasite, *Rhopalicus tutele* and a clerid predator, *Thomasimus formicarius* shipped from Austria in 1975. (Milligan, R. H. (1978) *For. Timber Ins. N.Z.*, No. 29, 8pp.)



Pine woolly aphid on *Pinus patula*, Kenya



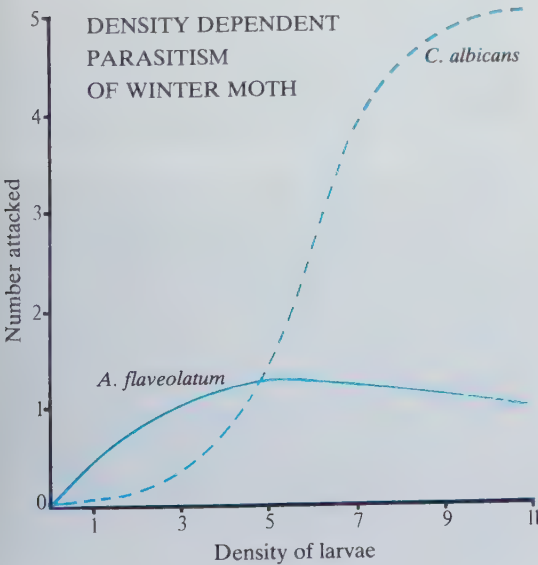
Pine woolly aphid on *Pinus* sp., Kenya

Red wood ants, efficient predators of defoliators which had been successfully redistributed in Italy, were shipped to **Quebec** by the CIBC during 1974–6 and are established. Their impact is yet to be fully realised.



Pine woolly aphid damage to *P. elliotti*, Kenya

The **European Winter moth** – *Operophtera brumata* – appeared in **Nova Scotia**, around 1930. It was effectively controlled at its point of entry by introduction of two parasites, *Cyzenis albicans*, a tachinid fly, and *Agrypon flaveolatum*, an ichneumonid wasp, from Europe during 1959–65. The two parasites are complementary as at high host densities, *C. albicans*, which oviposits near feeding damage of the host, is the most efficient parasite, with its rate of parasitism increasing as host density increases to as much as 80%, while *A. flaveolatum* which searches out the host larvae, is most efficient at low host levels. At its peak this insect killed about 95,000m³ of red oak per year, over a 10-year period in just two countries. The roadside harvest value of this wood is close to \$7,000,000 at current prices. Had its depredations continued, then more than 5.4 million m³ of oak



now standing in the province would probably have been killed, and the potential loss to the economy could have been far greater than the \$45,000,000 roadside value of the wood. By comparison, the cost of research related to the liberation of the parasites was just over \$560,000. (Embree, D. G. (1966) *Can. Ent.* **98**: 1159–1168. Embree, D. G. (1971) *Tech. Commun. CIBC* No. 4: 167–175.) Recently the winter moth has been discovered on Vancouver Island and in the States of Oregon and Washington in the USA. Releases of *A. flaveolatum* and *C. albicans* from Nova Scotia and Europe were made on Vancouver Island in 1979 and more releases are planned.

Shortly after the **Oak leaf-miner** – *Phyllonorycter messaniella* – was accidentally established in **New Zealand** in 1951, it became so abundant that the green leaf surface of introduced oaks was virtually destroyed, and fears were expressed that the leaf-miner would spread to native beeches. Studies were made in Europe which led to the successful introduction of *Enaysma splendens* and *Apanteles*

circumscriptus. A survey in 1970 showed that these parasites had provided substantial control, reducing infestations from over 40 miners per leaf to 2.3. miners per leaf. (Swan, D. I. (1973) *Bull. ent. Res.* **63**: 49–55.)

Other work on Canadian forest pests is too recent for assessment but shows promise. Against **Birch case bearer** – *Coleophora serratella* – parasites, *Campoplex* spp. and *Apanteles* spp., shipped in 1975 are established. Against **Birch leaf-mining sawfly**, two ichneumonids, *Lathrolestes nigricollis* (1974) and *Grypocentrus albipes* (1977), are expected to become permanently established. Against **Mountain ash sawfly** – *Pristiphora geniculata* – a parasite *Olesicampe* sp., shipped in 1978, is also breeding in the field.

The CIBC contributed in the early stages of the Australian campaign to control **Wood wasps** – *Sirex noctillio* – when the ichneumonids *Megarhyssa nortoni* and *Ibalia ensiger* sent from North America in 1962–64 became established.

Other natural enemies established against tree pests include:

Pest	Natural enemy	From	To	Date
<i>Clastoptera undulata</i>	<i>Carabunia myersi</i> <i>Uscanoidea nigriventris</i>	Jamaica	Bermuda	1964
<i>Hypsipila</i> spp.	<i>Trichogrammatoidea robustae</i>	India	Trinidad	1972
<i>Fiorinia theae</i>	<i>Aphytis theae</i>	India	Florida	1975

Weeds

The spectacular success against **prickly pears** in Queensland during the 1930s was repeated in many other areas. In the West Indies the CIBC achieved complete control of *Opuntia tricantha* and other species in **Nevis** using the moth *Cactoblastis cactorum* introduced in 1958. Control has also been successful in **Antigua, Montserrat, US Virgin Islands and Grand Cayman Island**. In 1973 the moth was taken to St. Helena where it is reported to be spreading across the island.



Opuntia tricantha, Nevis, 1952

A similar major success in **Queensland**, against another noxious cactus, is in the making. **Harrisia cactus** – *Eriocereus martinii*, an escaped ornamental, has spread rapidly since 1935 forming impenetrable thickets on grazing land. The cost of chemical and mechanical control in one of the two affected districts was Aust.\$670,000 in 1978. Studies by the CIBC in Argentina over four years have made available biological control agents. Releases began in 1974 and results were so



O. tricantha destroyed by *C. cactorum*, Nevis, 1960



Cactoblastis cactorum larvae

encouraging that the authorities suspended chemical control measures in 1979. The successful agents are a mealybug, *Hypogeococcus festerianus* which kills entire plants within 3–4 years and a weevil, *Alcidion cereicola*, which rapidly destroys mature plants. It is hoped that these insects assisted by an active colonisation programme will produce substantial control by 1981 (R. E. McFadyen & A. J. Tomley, *in litt.*).



Harrisia cactus, Queensland



Alcidion cereicola destroys Harrisia cactus, Queensland

The tropical American *Cordia curassavica* or **Black sage**, accidentally introduced into **Mauritius** during the last century, became a weed of major importance. After three years' studies on its natural enemies in Trinidad, insects were shipped to Mauritius from 1947–50. A leaf-feeding beetle, *Schematiza cordiae* achieved spectacular control but a seed-wasp, *Eurytoma attiva*, was also introduced to reduce seed dispersal. (Williams, J. R. (1960) *Bull. ent. Res.* **51**: 123–133.) In Peninsular **Malaysia** it was a popular hedge plant but in recent years had become a nuisance in plantations. Biological control was recommended by Dr. F. J. Simmonds, who had made the original studies in Trinidad. Introductions of the two successful insects were made under his supervision in 1978. Within a year they had spread throughout the Peninsula and there are signs that the operation will be as successful as in Mauritius. Shortly afterwards the insects were introduced into **Sri Lanka** where there was a potentially serious situation with thickets developing near Colombo. *S. cordiae* at least is well established and will, it is hoped, do as well as it has elsewhere.



Schematiza cordiae larvae

Siam weed – *Chromolaena odorata* – is a major pest in parts of Asia in plantations and also on open ground where it forms impenetrable thickets. In spite of its common name it is of South American origin. The CIBC carried out extensive studies and recommended the tiger moth, *Ammalo insulata* for trial as a control agent. It was released in large numbers in Ghana, Nigeria, and India to no avail. In Sabah (Malaysia) it became established and persisted for several years, but its present



Siam weed

status is not known. It was released in coconut plantations in **Sri Lanka** at the end of 1973 with no great expectations, but within six months there was spectacular defoliation at the first release point. Further releases were made and by the end of 1975 some 850 ha were being repeatedly defoliated. It continues to spread and is putting increasing stress on the weed and should eventually achieve a useful degree of control. (Dharmadikari, P. R. *et al.* (1977) *Tech. Bull. CIBC* No. **18**, 129–135.)

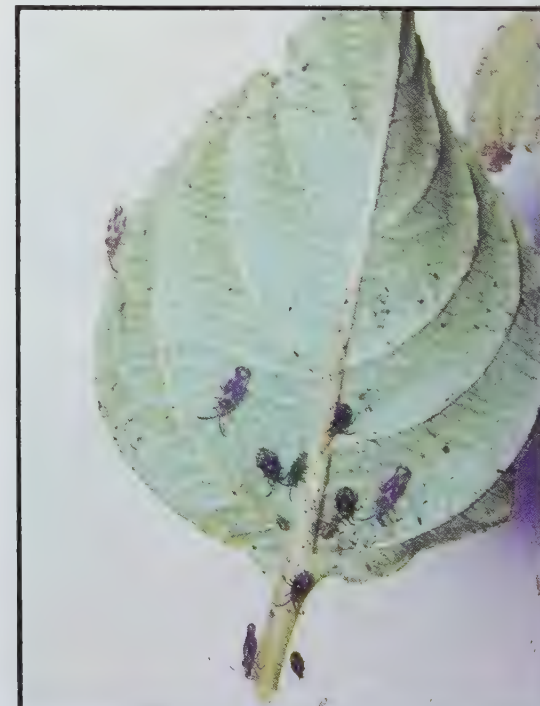
Because of their attractive flowers **lantanas**, from tropical America, have been planted throughout the warmer parts of the world as ornamentals and hedge plants. Forms of *Lantana camara*, with vigorous scrambling habit, have become major weeds in many countries. As well as producing impenetrable thickets the weed is poisonous if eaten by cattle and in some parts of Africa provides breeding places for tsetse flies. Biological control was pioneered by Hawaii in 1902. Until recently other countries followed this lead, introducing species which were successful in

Hawaii. The most famous, a lacebug, *Teleonemia scrupulosa*, has now been released in most affected areas, usually with little useful effect although it establishes readily and causes dry season defoliation. It has been most successful in an area of central **Uganda** where it was released in 1963 with assistance from CIBC. After three years during which a spectacular population explosion took place a combination of the lace bug and burning the weakened plants had cleared the area and returned a former thicket to cultivation. (Greathead, D. J. (1971) *Tech. Commun. CIBC*

No. 5, 23–25.) Elsewhere a combination of insects has been necessary to achieve control, a leaf mining hispine, *Uroplata girardi*, is one of the most useful, being readily established. The CIBC continued to play a part in promoting lantana control and has assisted in the supply of control agents to Tanzania, Ghana, Zambia, India, Fiji and the Cook Islands, in liaison with CSIRO Australia which has made available further species following research in South America.



Lantana camara



Teleonemia scrupulosa

The successful control of **Puncture vine** – *Tribulus cistoides* – in the USA by European weevils, *Microlarinus* spp. was repeated in **St. Kitts** and subsequently in **Nevis** by the CIBC after the release of *M. lypriformis* obtained from Hawaii in 1966.

As a result of extensive investigations in Europe insects are being introduced into North American and other temperate regions against several noxious species of thistles and knapweeds of European origin.



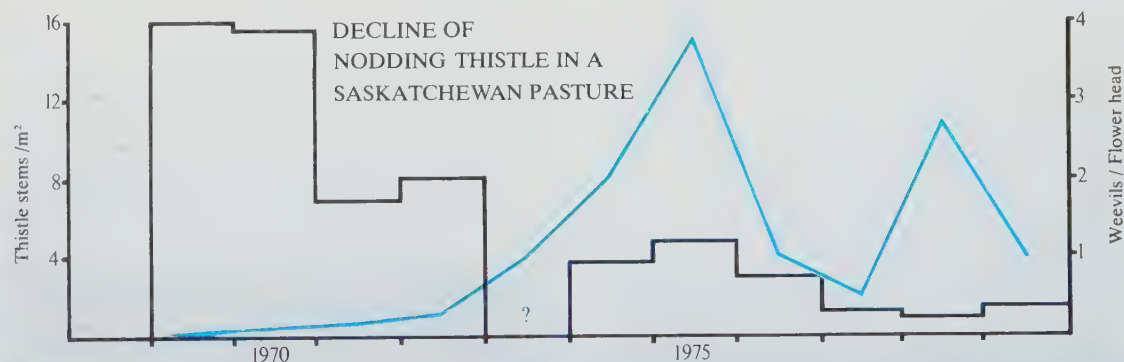
Puncture vine



Puncture vine, St. Kitts, 1966

Nodding thistle – *Carduus nutans* – has spread rapidly to form pure stands in uncultivated grasslands of the **Canadian prairies**. The seed-head weevil *Rhinocyllus conicus* was released in Saskatchewan and Ontario in 1968 and subsequently distributed to Manitoba, Quebec and British Columbia. At one release site in a Saskatchewan pasture, the density of the thistle gradually declined by about 90%. Reports indicate that the weevil has visibly reduced the density of another European thistle, *C. acanthoides*, in Ontario pasture lands. *R. conicus* was also sent to

the USA in 1969 and released in **Virginia** where it has been more successful and is credited with giving substantial control of nodding thistle. To further stress the thistle the rosette-crown weevil, *Ceutorhynchidius horridus* was released in 1975; it has survived in small numbers in Saskatchewan. (Harris, P. & Zwölfer, H. (1971) *Tech. Commun. CIBC No. 4*: 76–79. Kok, L.T. & Surles, W. S. (1975). *Environ. Ent.* 4: 1025–1227.) *R. conicus* was also released in New Zealand in 1968 and 1973. It is established and shows promise as a control agent (Ivens, G. W. (1979) *N.Z. J. Agric.* 138: 16–17.)



St. Kitts, 1968, after control of Puncture vine



Nodding thistle

Creeping thistle – *Cirsium arvense* – is another species which has become an important weed in **Canada**. A root-crown weevil, *Ceutorhynchus litura* introduced in 1967, has been released and is established at sites from British Columbia to New Brunswick. A stem gall fly, *Urophora cardui*, released from 1974–6, is well established in Ontario, Quebec and New Brunswick. To date they have only been partially successful, but populations of the control agents are still increasing.

Diffuse and Spotted knapweeds – *Centaurea diffusa* and *C. maculosa* – have occupied large areas of dry grasslands in western North America. Losses in forage yields in **British Columbia** are estimated at \$350,000 annually and are expected to increase to \$58 million as the weed spreads into the prairies. Two seed-head gall flies, *Urophora affinis* and *U. quadrifasciata*, released in 1970–72 increased rapidly and have reduced seed production from 30,000 – 40,000 seeds/m² to 1,500/m² (P. Harris *in litt.*). This has not reduced knapweed density on the study sites but may have done so where seed predation by vertebrates or competition with grasses is greater. (Harris, P. (1980) *Z. angew. Ent.* **89**: 504–514.) To further stress the knapweeds, a seed-head moth, *Metzneria paucipunctella* has increased to attack over a third of the heads in the release area (J. H. Myers *et al. in litt.*).

Studies in Pakistan on related species indicated promising candidates for the control of **Russian thistle** – *Salsola iberica* in **California**. The first to be introduced, the case-bearer moth, *Coleophora parthenica*, released in 1973, is now widely established in the western USA and studies on its impact are being made. A second species *C. klimeschiella*, introduced 1975–7, is already well established at the release sites in California, Washington and Idaho, but a colony released in Saskatchewan was unfortunately wiped out by floods. (Hawkes, R. B. & Mayfield, A. (1978) *Proc. IV Int. Symp. biol. Contr. Weeds, Florida*: 113–116.)

The toxic perennial weed **Tansy ragwort** – *Senecio jacobaea* – is established on both **Canadian coasts**, and has recently been spreading in southern Ontario. Releases of the cinnabar moth, *Tyria jacobaeae* were started in 1961 but establishment was not obtained until 1965. Subsequently moth



Cinnabar moth larvae

populations on both coasts increased and now defoliate the weed. On the east coast the weed declined at the release sites to about 0.1% of its former density but did not on the west coast. The flea beetle *Longitarsus jacobaeae* released in British Columbia from 1971–4, has become numerous at the release sites and is expected to supplement the stress imposed by the cinnabar moth. (Harris, P. *et al.* (1975) *Can. Ent.* **107**: 913–918. Harris, P., *et al.* (1978) *Proc. IV. Int. Symp. biol. Contr. Weeds, Florida*: 174–190.)

The spread of **St. John's wort** – *Hypericum perforatum* – caused concern in **British Columbia** in the 1940s, in view of its ability to dominate grasslands in the western United States. To attempt to check it the leaf feeding beetles *Chrysolina quadrigemina* and *C. hyperici* were released in British Columbia in 1952 but remained at low densities at the release sites for up to 12 years after which they increased rapidly to reduce weed density by up to 98% within three years. At some sites the weed has remained sparse with a small population of beetles but at others there have been cycles of weed and beetle abundance which seem to be caused by periodic winter kill of the weed and its subsequent return from seed after death of the beetles. Also the weed has continued to spread on the infertile glacial soils of the east Kootenays. *C. quadrigemina* reduced *H. perforatum* to 0.2% at an Ontario release site and *C. hyperici* has become numerous in one area of **Nova Scotia** but so far neither species has done well in New Brunswick. To further stress the weed in the east Kootenays, *Aphis chloris* was released in 1979. (M. G. Maw, *in litt.* Harris, P. & Peschken, D. (1974) *Can. Agric.* **19**: 13–15. Harris, P., *et al.* (1969) *Can. Ent.* **101**: 101–115.)

Waterweeds

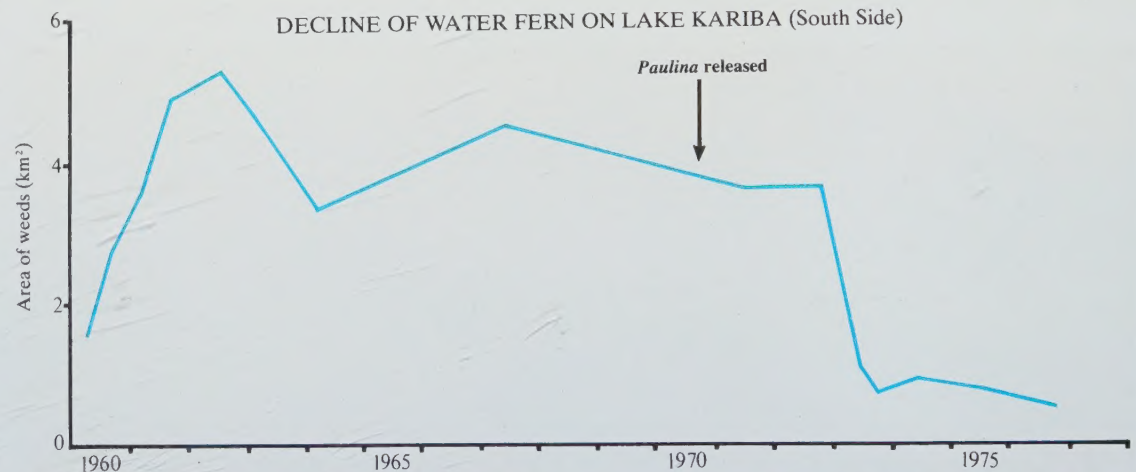
Biological control of floating waterweeds was pioneered by the CIBC which carried out surveys in South America. The work on **Waterhyacinth** – *Eichhornia crassipes* – has been exploited by the USA which after further studies has several natural enemies established in Florida. The CIBC is at present assisting in a programme in the Sudan to rid the Nile of this menace. However, one of the natural enemies, a mite *Orthogalumma terebrantis*, sent from Trinidad to Zambia in 1971 is established there.



Water hyacinth

Water fern – *Salvinia molesta* – is of major importance in lakes and dams in Africa, Asia and the Pacific. It forms extensive floating mats which shut out light suppressing fish culture, impede boats and choke hydroelectric power stations and irrigation ditches. One natural enemy investigated

by the CIBC, an aquatic grasshopper, *Paulinia acuminata* has been most widely released. It was liberated on **Lake Kariba** in central Africa in 1971, after three years' studies, and became established. An effect was noticed by 1973 when the grasshopper was widespread and reaching densities of 20 m^{-2} .



Water hyacinth in Nile



Neochetina eichhorniae, damage by adults

Its preference for young growth limited spread and by mid-1976 the area on the south side covered by weed had fallen to 39 km², only 7% of the 1962 maximum in parallel with the build-up of the grasshopper. (Mitchell, D. S. & Rose, D. J. W. (1979). *PANS* 25: 171-177.) Releases elsewhere in Africa have resulted in the probable permanent establishment of the grasshopper in the Chobe River, **Botswana**. In **Fiji** releases of *P. acuminata* in

late 1975 and a pyralid moth, *Samea multiplicalis*, in 1976 have been successful in that the insects survived severe floods in 1978 when most of the weed was washed out to sea, and appear capable of keeping the residual weed mats in check. Releases of one or both of these insects and a weevil, *Cyrtobagous singularis* have been made, continue or are contemplated in Africa, India and elsewhere spurred by these encouraging results.



Cyrtobagous singularis

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